SLOT ANTENNA

BY

COLM KENNEDY AND DUANE Mc NUTT

BACKGROUND

The field of design is antennae for aircraft. In particular the field of design is shunt antennae. Shunt antennae have been used many places over the years. Basically the term refers to antennae, which are grounded at one end and fed low voltage and high amperage radio frequencies to cause radio frequency (RF) propagation.

Slot antennae fall into this category and they have been used on aircraft vertical and horizontal tail surfaces for many years. Their use on tail surfaces causes the whole tail to become a radiator and results in an almost equal 360-degree propagation of the RF signal. The entire tail surface becomes a radiator of the RF signals from the antenna, which increases the surface area of the antenna and increases the propagation of the RF signal in all directions.

Prior to the advent of slot antennae, commercial jet transport aircraft were equipped with "long wire" antennae whose high-speed drag was unacceptable, though used, on the early jets. These antennae were required to communicate on high frequency ("HF"), a band of frequencies in the range of 2mhz-20mhz, designated by international treaty and used for contacts over 200 miles. 2182 kilohertz is the international distress signal. Other types of aircraft currently use the long wire antenna to attain this lower range.

A vertical stabilizer HF slot antenna, which covered most of the band, was developed by Eastern Air Lines (EAL) for the B727. The design was apparently never patented and is a version that is found on every Boeing today. Its failure to cover the lower frequencies is due to its shorter length, which is limited by stabilizer space considerations. To feed it efficiently its tuners are mounted in the vertical stabilizer, which is a very harsh environment of temperature and pressure extremes.

Most jets now flying internationally use tail mounted HF slot antennae, some with more success than others. No one had produced an HF slot antenna mounted anywhere other

than the tail and it was believed by the airplane industry that any antenna placed elsewhere would be ineffective. Industry wisdom has for years held that for slot antenna to be effective they had to be part of the empennage to get it to properly radiate the signal. The empennage is the tail fin area with the vertical stabilizer and the horizontal stabilizer.

The Lockheed Hercules C-130 models A thru H and its civilian version L-382 were all produced with two antenna masts and two long wire antennae terminating high on the vertical stabilizer. On the later version, Lockheed Hercules C-130 "J" model, Lockheed incurred significant development costs to modify the empennage structure at the base of the vertical stabilizer to make room (physically and electronically) for a "notch"(shunt) antenna because it was believed there was nowhere else for the antenna to go. Due to the particular constraints of the existing Hercules stabilizer anti-icing system it was believed by the industry that the base of the vertical stabilizer was the only location for a notch antenna. All models of the Hercules have this stabilizer anti-icing system, therefore it is a constraint to the location of mounting an antenna that must be considered on all models. This notch antenna

installation is available from Lockheed on older "A"-"H" models for retrofit at a price of approximately $250,000 with a long down time. The latest model Hercules C-130"J" are manufactured with this style notch antenna at a price buried in the purchase price.

Avionics equipment on aircraft is mounted so that it is constantly surrounded by conditioned air in its ideal environment. Tuners placed high in the tail are operating under difficult conditions, which occurs with the previous design for the Hercules C-130"J". Significant efficiency benefits result from the closeness of the tuners to the antenna element. Shunt antennas work at a very low voltage of approximately 1.5 Volts and a high amperage of 75 Amps plus. This makes long feed lines from tuner to antenna counterproductive due to voltage drop and the consequent power loss. Vertical stabilizer mounted shunt antennae mandated mounting the tuners high in the stabilizer in non-pressurized, unheated, and inaccessible areas. It would be advantageous to mount the tuner units where they should be, inside and very close to the feed end of the antenna.

Therefore there is a need for a slot antenna that can be mounted away from the empennage area. Furthermore, the

tuners should be mounted in an interior environment with a short feed line from the tuners to the antenna element.

SUMMARY

An objective of the slot antenna is providing an antenna that can be retrofitted to existing Hercules aircraft in a location other than the empennage tail section of the aircraft.

Another objective is creating a better environment for the mounting of the tuners, which are often subjected to the extreme conditions of high altitude environments. This provides improved reliability and durability of the tuner components. Another objective is mounting the tuners in an easily accessible area. Installation costs, maintenance costs, maintenance equipment requirements and time are all significantly reduced by the improved accessibility.

Another objective of the slot antenna is creating an antenna structure that can be fed RF signals from the end remote from the empennage. The benefit of such a design is that it is much easier to mount the tuners in the improved environment of the cargo cabin roof area. An additional

benefit is that the RF feed line can be significantly reduced in length, which minimizes interferences and improves reception.

Another objective of the slot antenna is integrating the antenna into the existing dorsal fin of the aircraft, such that, the structural integrity of the fuselage is maintained. Due to the particular constraints of the existing Hercules stabilizer anti-icing system it was believed by the industry that a slot antenna could not be located within the dorsal fin. The industry believed that the base of the vertical stabilizer was the only location for a slot antenna.

Another objective is producing an economically viable alternative to the traditional long wire antenna. The benefit is significant reduction in air drag and the associated fuel costs that occur with the long wire antenna. 2182 kilohertz is the international distress signal. Other types of aircraft must use a long wire antenna to attain this lower range. The new design would be advantageous here for providing this capability on the "A-H" model Hercules, without the need for a long wire antenna.

Another objective of the slot antenna is a design that can be installed without additional down time during a routine A-1 or B aircraft maintenance check. This significantly reduces the loss of revenue that occurs with grounded airplane.

The slot antenna is mountable on the Hercules aircraft dorsal fin. The slot antenna includes a lower plate that forms a false spar, an upper plate adjacent to the lower plate, an antenna element, and a tuner operatively connected to the antenna element. The antenna element is integrated within the upper plate. The slot antenna includes a Radio Frequency feed line that operatively connects the tuners to the antenna element.

The tuner transmits radio frequency (RF) signals to the antenna element. The antenna element and the lower plate become charged by the RF signals. The antenna element and the lower plate are substantially separate by air, thus the charged upper plate and lower plate separated by the air insulator produce a capacitor effect.

The antenna element has a front-end that is facing towards the nose of the aircraft and a back-end that is closer to the tail of the aircraft. The tail of the aircraft forms the empennage. The antenna element forms three prongs; a center prong, a first lower prong and a second lower prong. The three prongs are connected at the back-end of the antenna element. The three prongs are substantially separated by a fiberglass plate throughout most of the length of the antenna element and at the front-end.

The center prong has a width dimension 'W1', which normally is between about 10 inches and about 6 inches. The first lower prong and the second lower prong have a width dimension 'W2', which is typically between about 4 inches and about 2 inches. In a preferred embodiment the first lower prong and the second lower prong are the same in width and are the same in length. The center prong has a length dimension 'L1' that is typically between about 120 inches and about 110 inches. The first lower prong and the second lower prong have a length dimension 'L2'. The lower plate has a length 'L3'.

The center prong has an apex. The apex and the lower plate are separated by a distance 'D1'. There is a relationship between the dimensions 'W1', 'W2', 'L1', 'L2', 'L3' and 'D1' that effects the coordinating of the upper plate and lower plate to function appropriately with the characteristics of the tuner. In one version that provides an RF signal that will radiate long distances, 'W1' is about 8.0 inches, 'W2' is about 3.0 inches, 'L1' is about 116.5 inches, 'L2' and 'L3' are about 134.5 inches, and 'D1' is about 7.5 inches.

There are one or more tuners mounted within the interior of the aircraft fuselage. The tuners are mounted on a tandem rack, which is a front and back arrangement of the tuners. Prior art designs used a side-by-side mounting of the tuners. The space restraints of the interior of the Hercules aircraft required the innovation of a new design for the tuner mounting rack.

The new design slot antenna when mounted in place of the crown skin on the dorsal fin of the Lockheed Hercules (after structural beef up of the fin) and when fed from the end most remote from the empennage, by tuners mounted in the cargo cabin, produces a level of all around HF

propagation never before experienced in an "A"-"H" model Hercules and does so over the entire 2mhz-20mhz of the HF band. It was necessary to provide structural strengthening of the dorsal fin, to compensate for the structural components that were modified or removed to provide sufficient space for the antenna parts. The shape and dimensions of various structural components within the dorsal fin were modified and became a part of the antenna.

The design of the antenna had to be tailored to fit the dorsal fin and (a) be responsive to the frequency band, (b) have inductive and capacitive properties compatible with the envelopes of the commercially available automatic tuners which have limited capabilities to tune in three functions (series and shunt capacitive tuning and series reactive tuning) and (c) be structurally acceptable as replacement equipment. To accommodate the capacitive requirements it was found necessary to install a false spar located above the structural replacement units.

The new design antenna can be provided and installed for less than 1/3 the price of the prior Lockheed retrofit design. The fuel savings resulting from the antenna drag reduction is calculated to pay for it and its installation

in two years of commercial cargo flying. The fuel saving is based on comparison to the frictional drag of the Hercules existing long wire antenna. The slot antenna will support the digital automatic position reporting system now going into operation worldwide, which could not be done with the old long-wire system. The international accepted protocol for automatic reporting makes technical demands on the system not supportable by the long wire antenna tuning time capabilities. The antenna and it's supporting system is so designed it can be installed without added down time during a routine A-1 or B aircraft maintenance check (5-7 days).

A tandem mounted rack was designed to accommodate feeding the antenna from the end remote from the empennage. Prior designs were the traditional side-by-side double mounted rack. The repositioning of the antenna tuners within the interior of the fuselage keeps them in a much better environment. Reliability of the equipment is improved when mounted in the pressurized cabin with conditioned air temperatures versus outside ambient temperatures that range from +130F to -40F. The outside air pressure varies significantly over the range of sea level to 30,000' that are normal flying conditions. The

interior location allows service or exchange from inside the fuselage with no more required than mounting a stepladder inside in lieu of a tall cherry picker outside.

The design of the tandem mount rack for the tuners allows them to be mounted in the optimum electrical location without interference from control cables and load drop system components in the upper cabin area while allowing the critical RF feed line to be very short at about 5.5″ versus 30″ on previous designs. With good HF propagation conditions, worldwide communications can be anticipated from cruising altitudes.

The placement of slot antenna within the dorsal fin required the removal of existing support structure and the installation of a false spar that serves as the lower plate of the antenna, which balances the antenna electronically. The replacement of rib structural mounts to create a bottom cavity is necessary. Removal of the rib structure was necessary because its effect as a capacitive ground would be too much, due its proximity to the antenna element. Modified supports items are installation for structural reasons and installation of the cover pieces brought the value of the capacitive component of the antenna assembly

up to where the tuners could handle it. The antenna is tweaked by dimensional adjustments to conform to the preset envelope of characteristics required by the standard tuner. The overall design allowed for feeding the antenna from the end remote from the empennage, which was previously believed by the industry to be unattainable. Positioning the antenna tuners in the cargo cabin roof area created a better environment and higher electronic efficiency.

The interior mounting provides ease of maintenance service. Units can be changed without special hi-lift equipment, which is normally only available in an aircraft maintenance hangar. The initial retrofitting of the slot antenna into the aircraft is performed in shorter time period due to the tuners being mounted on the interior versus high in the tail. Structural modifications and attachment methods to the interior of an aircraft are not as critical as modifications affecting the exterior surface. Smooth exterior surfaces must be carefully maintained to minimize the air drag and separation of exterior panels at high speeds.

The length of the antenna element makes the antenna 30 percent longer than the traditional Boeing antenna. The

longer antenna length allows going to the bottom of the transmission frequency band, which is important for military applications. The bottom of the frequency band is particularly required for Navy and Coast Guard usage. 2182 khz is the international marine HF emergency frequency and many close frequencies are used in ship-to-ship and ship-to-shore traffic control.

Although the present invention is briefly summarized, a fuller understanding of the invention can be obtained from the following drawings, detailed description and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with reference to the accompanying drawings, wherein:

Fig. 1a is a top/side perspective view.

Fig. 1b is a cutaway view along the center of the antenna element.

Fig. 2a is an exploded top/side perspective view.

Fig. 2b is a top/side perspective view.

Fig. 2c is a top/side perspective view.

Fig. 3a is a top/side perspective view of the lower plate.

Fig. 3b is a Prior Art top perspective view of the structural ribs.

Fig. 3c is a top/side perspective view.

Fig. 4 is a top/side perspective view of the tuner.

Fig. 4b is a top/side perspective view of tuner the location.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to figs. 1a and 1b, which illustrate a slot antenna **10** mountable on the Hercules aircraft **102** dorsal fin. The slot antenna **10** includes a lower plate **12** that forms a false spar **14**, an upper plate **16** adjacent to the lower plate **12**, an antenna element **20**, and a tuner **22** operatively connected to the antenna element **20**. The antenna element **20** is integrated within the upper plate **16**. The upper plate **16** that contains the antenna element **20** replaces a portion of the crown skin of the fuselage. The upper plate **16** forms the shape of the existing crown skin, which it replaces. The tuner **22** transmits radio frequency

(RF) signals to the antenna element **20**. The antenna element **20** and the lower plate **12** become charged by the RF signals. The antenna element **20** and the lower plate **12** are substantially separate by air **100**, thus the charged upper plate **16** and lower plate **12** separated by the air insulator produce a capacitor effect.

The antenna element **20** has a front-end **24** that is facing towards the nose of the aircraft **102** and a back-end **26** that is closer to the tail **104** of the aircraft **102**. The tail **104** of the aircraft **102** forms the empennage **108**, which includes the vertical stabilizer **110** and the horizontal stabilizer **112**. The antenna element **20** forms three prongs; a center prong **30**, a first lower prong **32** and a second lower prong **34**. The three prongs are connected at the back-end **26** of the antenna element **20**. The three prongs are substantially separated by a fiberglass plate **36** throughout most of the length of the antenna element **20** and at the front-end **24**. The first lower prong **32** and the second lower prong **34** are in grounded contact with the lower plate **12** and the sides of the fuselage of the airplane. Large bolts and other metallic structural components provide grounding contact between the antenna

and the empennage **108** area, which provides a path for the RF signals to travel.

The antenna element **20** is grounded at its back-end **26** near the empennage **108**. The tuner **22** feeds energy into the front-end **24** of the antenna element **20**. The RF signal energy radiates through the antenna element **20** towards the grounded end of the antenna element **20** and into the empennage **108** at the tail **104** of the airplane. The vertical stabilizer **110** and the horizontal stabilizer **112** are at right angles to each other, thus they provide excellent radiation of the RF signal in multiple directions.

The center prong **30** has a width dimension 'W1', which normally is between about 10.0 inches and about 6.0 inches. In a preferred embodiment the width dimension 'W1' of the center prong **30** is about 8.0 inches. The first lower prong **32** and the second lower prong **34** have a width dimension 'W2', which is typically between about 4 inches and about 2 inches. The width 'W1' is measured as a circumference. In a preferred embodiment the first lower prong **32** and the second lower prong **34** are the same in width and are the same in length. The width dimension 'W2' of the first

lower prong **32** and the second lower prong **34** is about 3.0 inches.

The center prong **30** has a length dimension 'L1' that is typically between about 120 inches and about 110 inches. About 116.5 inches is a preferred length for dimension 'L1'. The first lower prong **32** and the second lower prong **34** have a length dimension 'L2', which is about 134.5 inches. The lower plate **12** has a length 'L3' that is also about 134.5 inches. The length of the antenna element **20** determines the frequency you can achieve. The longer the length the lower the attainable frequency, which provides a significant advantage for the present design.

The center prong **30** has an apex **38**. The apex and the lower plate **12** are separated by a distance 'D1'. There is a relationship between the dimensions 'W1', 'W2', 'L1', 'L2', 'L3' and 'D1' that effects the coordinating of the upper plate **16** and lower plate **12** to function appropriately with the characteristics of the tuner **22**. In one version that provides an RF signal that will radiate long distances, 'W1' is about 8.0 inches, 'W2' is about 3.0 inches, 'L1' is about 116.5 inches, 'L2' and 'L3' are about 134.5 inches, and 'D1' is about 7.5 inches.

Referring to figs. 2a, 2b, and 2c, the upper plate **16** with the antenna element **20** replaces the crown skin along a portion of the dorsal fin. Previous designs had the antenna located within the empennage **108** area and it was believed by the industry that an antenna mounted in the dorsal fin area would not be operative.

Fig. 2a shows an exploded view with the upper plate **16** removed from the dorsal fin area. The lower plate **12** is separated into three pieces. The lower plate **12** forms apertures **41** that provide for ease of access for installation and removal of the lower plate **12**. The apertures **41** also provide ventilation and access for inspection of the underlying components. Fig. 2b shows the tail **104** fin area of the aircraft **102** with the dorsal fin **106** area adjacent and in front of the tail **104** fin.

Fig. 2c has the radio frequency feed line **40** connected between the tuners **22** and the antenna element **20**. The tuners **22** are mounted near the antenna element **20**, thus power losses are minimized. The interior of an aircraft **102** is subjected to significant electro-magnetic fields that tend to interfere with the RF transmissions. Locating the tuners **22** close to the antenna element **20** is an

advantage and contributes to increased transmission distances. RF transmissions over significant distances have been achieved with this slot antenna **10** innovation. The fiberglass plate **36** forms an access cutout **37** for access to the feed line **40**. An access cover **39** provides a tight seal over the access cutout **37**.

Referring to figs. 3a, 3b, and 3c that illustrate the modifications made to the aircraft **102** structure to accommodate the slot antenna **10**. Fig. 3b shows the existing dorsal fin support structure prior to the modifications. The numerous support ribs **52'** are rounded or elliptical in shape. Fig. 3c illustrates the dorsal fin structure after the support ribs **52** modifications. The new ribs **52** are reduced in height and flat along their upper edge. A false spar **14** is created when the lower plate **12** is mounted on top of the ribs **52**. The reduction in rib height is needed to create a separation distance between the lower plate **12** and the upper plate **16** for the proper functioning of the antenna. The lower plate **12** is divided into three sections.

Referring particularly to fig. 3c, the lower plate **12** has a top surface **44** that is substantially flat. The lower

plate **12** comprises three separate sections that are a first section **46**, second section **48** and third section **50**. The three section **46, 48, 50** are easily removed and reattached during maintenance routines. The tuner **22** transmits radio frequency signals to the antenna element **20**, which radiate towards the grounded back-end **26** of the antenna element **20**. The back-end **26** is grounded near the empennage **108** and the RF signals will tend to radiate into the empennage **108** area. The antenna element **20** and the lower plate **12** produce a capacitor effect.

Referring to figs. 4a and 4b, the slot antenna **10** includes a Radio Frequency feed line **40** that operatively connects the tuner **22** to the antenna element **20**. The feed line **40** has a length "L4", which is about 5.5 inches. The tuner **22** is connected to the front-end **24** of the antenna element **20**. There are one or more tuners **22** mounted within the interior of the aircraft **102** fuselage. The tuners **22** are mounted on a tandem rack **42**.

Prior art designs (not shown) used two side by side mounting racks for the tuners **22**. The space restraints of the interior of the Hercules aircraft **102** required the innovation of a new design for the tuner **22** mounting rack.

The tandem rack **42** places the tuners **22** front to back of each other. This arrangement allows for two tuners **22** to both be fed directly into the same feed line **40**. The interior mounting allows easy access for maintenance and replacement of the tuners **22**. The tandem rack **42** fits into a much tighter space than prior mounting rack designs.

The entire design of the slot antenna **10** is uniquely suited for retrofitting on the dorsal fin **106** of the Lockheed aircraft **102** Hercules Models 'A-H'. The slot antenna **10** has many advantages including: an improved inside environment for the tuners; a shorter RF feed line connected to the end remote from the empennage, which improves efficiency; reduced air drag; economically viable installation, reduced maintenance time and reduced maintenance costs.

Although the present invention has been described in considerable detail with regard to the preferred versions thereof, other versions are possible. Therefore, the appended claims should not be limited to the descriptions of the preferred versions contained herein.